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This TOP describes the techniques, procedures, and general outline required to assess the effects of nuclear thermal and airblast environments on Army materiel. Test preparation, execution, and documentation are covered in this TOP. The nuclear thermal and airblast environments and effects are described in the appendices.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

TEST OPERATIONS PROCEDURE (TOP) 1-2-619 31 July 1996
AD No.

NUCLEAR THERMAL AND BLAST HARDNESS VALIDATION TEST

1. SCOPE. This Test Operations Procedure (TOP) outlines the procedures and facilities necessary to perform a nuclear thermal and blast hardness validation test. The hardness validation principles covered in this TOP may be applied to the hardness assessment of major weapon systems, subsystems, and line replaceable units. Appendix A provides a summary of the Department of Defense (DoD) Instruction 5000.2 on the acquisition of nuclear survivable systems, and Appendix B briefly describes the various approaches used to achieve and maintain nuclear survivable systems. Appendices C and D provide a brief description of the nuclear thermal and blast environments.

2.0 FACILITIES AND INSTRUMENTATION

2.1 Facilities

2.1.1 The selection of the simulation facility required to perform a thermal and/or blast test will be primarily driven by

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the test item's nuclear survivability criteria levels, expected type of loading response, significance of synergistic effects, importance of ground motion, and the size of the test item. The Guide to Nuclear Weapon Effects Simulation Facilities and Techniques-1992 Edition[1*] provides summary information on 262 nuclear weapons effects simulation facilities in the United States.

2.1.2 The following list outlines the types of facility characteristics that will be necessary to perform thermal and airblast testing.

Facility	Requirement
Thermal Radiation Facility	Capability to simulate a nuclear thermal pulse over small test areas (See Appendix C)
High Explosive Detonation Facility	Capability to simulate over large test items the peak static overpressure, small yield dynamic pressure, and ground shock environment produced by a nuclear weapon detonation (See Appendix D)
Shock Tube Facility	Capabillity to simulate peak overpressure of small yields for small test items that do not translate or require ground shock
Shock Tube or High Explosive Detonation Facility with a Thermal Radiation Source	Capability to simulate the combined nuclear thermal and blast environment

[1*]Superscript numbers/letters correspond to those in Appendix G, References.

Large Blast Thermal (LB/TS)	Capability to Simulator realistically simulate for large test items the peak overpressure, dynamic pressure, and associated duration of weapon yields under 300 kT; Capability to simulate a thermal/blast synergistic environment

2.1.3 It must be noted that the environment provided by a simulation facility will typically not meet all of the criteria parameters specified by the test item's Nuclear Survivability/ Hardening Criteria Document. Therefore, a special effort must be taken to select a facility that will provide the best approximation to the criterion parameter posing the most significant threat to the test item, and significant analysis must be performed to compensate for the shortcomings of the test environment and impacts on test results.

2.2 Instrumentation

2.2.1 The following list outlines several of the major environmental parameter measurement requirements and the accuracy that is recommended for each measurement. Each individual test's purpose and test item configuration will determine the actual parameters measured and their accuracy requirements. Some test facilities may require the user to provide the test item instrumentation and installation while others may provide this service for an additional fee.

Device for Measuring	Measurement Accuracy
Temperature	$\pm$5°C
Fluence (total thermal energy)	$\pm$10% cal/cm^2
Flux (maximum irradiance)	$\pm$10% cal/cm^2-sec
Displacement (horizontal, vertical, roll)	$\pm$1 cm $\pm$1 degree

Acceleration	±10% g
Strain	±10% m/m
Overpressure	±10% kPa
Duration	±10% sec

2.2.2 The facility's data recording instrumentation must have enough channels to accommodate the test's and environments' data requirements. The data recording rate (samples/second) must be capable of recording the test item's response rate. For analog systems, the recording capability must be twice the system's response frequency, and for digital recording, the sample rate must be eight times the system's response frequency. The instrumentation measuring the test environment must be capable of accurately recording all changes in the test environment. The data output format must also be considered when selecting a test facility; the data output format must be compatible with the tester's data reduction capabilities.

2.2.3 Still and motion photography or video support must also be available where applicable to document the pre-test setup, the test item's real time response to the test environment, and the test item's post-test configuration. Video and high speed cameras are usually used to monitor a test item's response during the test.

3.0 <u>REQUIRED TEST CONDITIONS</u>

3.1 <u>Pre-test Analysis</u>

3.1.1 The test item must be analyzed to identify mission critical components which are most likely to be susceptible to the thermal and blast environments as specified in the applicable Nuclear Survivability/Hardening Criteria document. Once these components are identified, they are listed as Hardness Critical Items (HCI). All possible test item configurations must be examined to determine which configurations pose the most probable and the worst case exposure scenario.

3.1.2 Analysis should include modeling the test item in the most probable and worst case configurations at the time of event using analytical or numerical methods to predict the item's worst case response to the thermal and blast environments. The following issues should also be addressed during the pre-test analysis.

a. The test item's functional requirements must be identified and documented. A functional checkout procedure and a failure criteria based on mission performance requirements must be established. The acceptable and unacceptable risks must be identified and used in conjunction with other pre-test analysis results to determine if more than one test item configuration/orientation should be used during testing.

b. The design safety margins of all HCIs are a major consideration when determining the test environment levels and identifying the number and type of test samples required. Above criteria testing may be used to confirm design safety margins and increase test survivability confidence which is otherwise low due to a limited number of test samples or production configuration control limitations. The above criteria test levels should fully exercise the design safety margins for the airblast and thermal environments. As a minimum, pre-test analysis should be performed at 1.3x the most significant environment parameter, usually peak overpressure, on the most probable worst case configuration/orientation.

c. Test data requirements and instrumentation type and placement should be defined to accurately monitor the response of potentially susceptible components and to enable the evaluator to correctly analyze the test results.

3.1.3 The pre-test analysis must also address the synergistic effects on the test item resulting from exposure to realistic, combined nuclear thermal and blast environments.

a. If a test item is subjected to the nuclear thermal environment and then to the nuclear blast environment in the proper time sequence to realistically approximate an actual nuclear environment, the test item's response will be different than if it was subjected to these environments as two separate tests. This happens because the yield strength of a structural material is lowered by a significant increase in the material's temperature.

b. An analysis must be performed to determine if the yield strength of the materials used in the test item will be significantly affected by the expected rise in temperature and/or thermal shock due to a nuclear thermal environment. The scope of testing may be reduced if applicable test results are available from previous testing on similar components/materials.

3.1.4 The pre-test analysis results will provide the information necessary for developing the actual test setup, test levels, and data instrumentation requirements. The test setup must include testing the item in all the configurations identified as posing an unacceptable risk and/or having a susceptibility to the synergistic effects of the combined nuclear thermal and blast environments.

3.2 Test Hardware and Instrumentation

3.2.1 The quantity of test items required and the acceptable test item's configuration (prototype or production) are determined by the specific nuclear environment being tested, the test program/test facility schedules, hardware availability, and the size of the simulation facility's test volume. A baseline configuration for the test item must be established prior to the start of testing to identify and evaluate all hardening features, both deliberate and inherent.

a. Completely functional prototypes or production versions of a test item may not be required for testing if the configuration differences are transparent to the test environment. For example, a dynamic, mass simulator of a system may be used to perform airblast testing, or subassemblies and components may be used to conduct thermal testing. Representative panels of an exposed area on the test item may also be used to conduct thermal testing. However, changes in the production design must be monitored to ensure that the item's nuclear thermal and blast hardness are not compromised to a level where survivability with confidence is lost.

b. The selected simulation facility's test volume must be able to accommodate the test item, or the test item may be configured (maintaining a representative configuration) to fit in the facility's test volume. Area blockage should not exceed 10 percent of the available cross-section if a shock tube is used.

c. Nuclear thermal and blast tests may be considered potentially destructive tests and usually are placed at the end of an item's test cycle. However, if the risk to mission accomplishment is high, or the test program milestone schedule or the test facility schedule do not allow series testing, additional or specific test item allocations will be required.

d. Another factor that will influence the number of test items allocated for nuclear thermal and blast effects testing is

the possibility of a test item catastrophically failing during testing. A catastrophic failure is one which does not allow a test item to continue testing within a reasonable amount of time and/or with minimal repairs. This situation should be accounted for by allocating backup units for the test effort.

3.2.2 Data instrumentation for the blast test (See para 2.2.1) should include pressure transducers to measure the free field overpressure, free field dynamic pressure, test item internal cavity overpressures, and associated pressure durations; strain gages to measure the strain induced by the blast environment on specific test item components; displacement devices to measure test item deformation or translation; accelerometers to measure the forces induced on specific test item components; and high speed motion picture photography or video to record the real time test item response. These instruments should be positioned at locations on the test item based on the pre-test analysis. Data transmission is normally through twisted pair cable, and input to adjustable gain instrumentation amplifiers and transient data recorders with a minimum operating bandwidth of 200 kHz. The pre-test analysis should provide the gain settings for the amplifiers. The data generated by the free field instrumentation will be used to evaluate the simulated blast environment against the blast criteria specified for the test item.

3.2.3 Data instrumentation for the thermal test should include thermocouples to measure the free field, test item, and test item internal cavity temperatures; and calorimeters to measure the thermal fluence and flux. These transducers and calorimeters should be positioned at locations on the test item based on the pre-test analysis. The free field waveform generated by the calorimeters will be used to evaluate the simulated thermal radiation environment against the thermal criteria specified for the test item.

3.3 Test Plan

a. A detailed test plan must be written based on the test item's specific requirements, results of the pre-test analysis guidelines given above, and addressing the test setup checkout procedures listed in paragraph 4.0.

b. The detailed test plan should be written by the Tester based on the evaluation plan and test design plan, and then coordinated with the Program Manager, the Independent Evaluator, the User, and the test item Manufacturer.

c. The test plan must also address all personnel safety issues pertaining to the testing of the item. Necessary safety measures for the operation of the test item as identified in it's Safety Assessment Report must be clearly identified and followed in the test plan.

d. All hazardous materials contained in the test item must be identified, and the test plan must include the appropriate recovery and clean up procedures for each hazardous material in case of a spillage or dispersion during testing. Material Safety Data Sheets (MSDS) for all the applicable test item materials/equipment must be referenced in the test plan and available at the test site.

e. All training requirements must be identified in the test plan.

f. Analytical procedures for comparing the test and environmental data must be clearly stated in the test plan. Procedures must describe how the actual test environment data will be compared to the required environment to determine fidelity and impacts on test item response.

g. The test plan should describe all data required to evaluate adequacy of test environment and hardening features, and response of test items. Procedures must describe how to correct test item responses to the criteria environment, and relate the corrected results to the baseline item's configuration. Finally, the procedures should describe how impacts on mission performance will be evaluated.

4.0 TEST PROCEDURES

4.1 Nuclear Thermal

4.1.1 Test Setup

a. Baseline the test item by conducting a visual inspection of the surfaces to be exposed to the thermal pulse and performing any applicable functional and/or visual checkouts. Photographs/videos of the test item should be taken to document the item's pre-test condition. Document the type and condition of any thermal hardening measures used in the test item's design such as ablative paint or reflective coatings/covers. In the event that non-production material is used in or as the test item, document the differences between that material and the

expected production items.

b. At the proper test location, place and secure the test item on the test bed in the configuration established by the pre-test analysis (para 3.1). Ensure the test item is placed such that the test can verify that the designed thermal hardening measures do provide the intended protection from the thermal environment.

c. Instrument the test item according to the data instrumentation requirements established during the pre-test analysis (para 3.2.3). Confirm the placement of the free field instrumentation, and verify that the data acquisition system is operational. All instrumentation (thermocouples and calorimeters) and data acquisition system calibration data must be documented. To the extent possible, baseline the test item again while in its test setup.

d. Document the test item placement and instrumentation locations by test layout drawings and/or taking photographs/video of the test bed setup.

e. Reverify that the simulation facility is set up to provide the correct environment levels for the test item/configuration being tested.

f. Confirm that the test item is in the proper operational mode; if applicable, perform any final checkouts.

g. Perform test.

h. Repeat above procedures for each test that is performed.

4.1.2 Post-test Checkout

a. Once it is safe to approach the test item, an overall visual inspection of the test item must be performed as soon as possible. The post-test condition of the test item should be recorded in a log book or data sheet and photographed/video taped.

b. The following should be inspected:

(1) The condition of the thermal hardening measures. Is ablative material or paint charred? Is ablative material or paint completely burned off? Is reflective coating/cover

damaged?

(2) The condition of the test item's main structure. Is the structure charred, flaming, or burned? Is the structure rigid, warped, or pliable? Is material/soot deposited on the test item? Did melting and/or frosting occur? Did cracking occur? Did color changes occur? Did the material bubble?

(3) The test item's functionality. If applicable, is the test item operational? If not, is it repairable? Does the test item meet the failure criteria established in paragraph 3.1.2a?

(4) Instrumentation condition. Are all gages mounted and intact? Are data cables properly attached and undamaged?

c. The results of all the post-test checkouts should be recorded using Test Incident Reports (TIRs); detailed procedures on handling and filling TIRs are contained in DA PAM 73-1, Part 1, Chapter 17[2]. A blank TIR is provided in Appendix E. "Good News" TIRs may be written to document successful results or completion of a test phase.

4.1.3 Data Required

a. Description and findings of the pre-test analysis and simulations.

b. Detailed description of the test item to include the following

(1) Serial number
(2) Serial numbers for subcomponents (if applicable)
(3) Dimensions
(4) Material Composition
(5) MSDS(s) (if applicable)
(6) Photograph/video of pre-test condition
(7) Mechanical drawings
(8) Operating status and recovery procedures

c. Detailed description of all inspections, performance and operational base line checks.

d. Detailed description of the test facility and the method used to produce the thermal radiation environment.

e. Results of the thermal radiation environment measurements with the fluence expressed in calories per square centimeter (cal/cm^2), flux expressed in calories per square centimeter per second (cal/cm^2-sec), time to maximum irradiance expressed in seconds, and pulsewidth full width/half maximum (FWHM) expressed in seconds.

f. Results of the data instrumentation measurements monitoring the test item response.

g. Results and photographs/video of all pre-test and post-test visual inspections and functional checkouts.

h. Copies of the TIRs.

i. Detailed description of test item configurations tested.

j. Detailed description of the data acquisition system to include calibration, accuracy, and percent error for all data acquisition equipment.

4.2 Nuclear Blast

4.2.1 Test Setup

a. Baseline the test item by conducting a visual inspection of the overall test item's configuration and specifically noting the condition of all the HCIs identified in the pre-test analysis (para 3.1.1). Any applicable functional checkouts must be performed during the test setup. Photographs/video of the test item should be taken to document the item's pre-test condition. Document the type and condition of any blast hardening measures used in the test item's design such as outriggers, guy wires, and protective armor/plates. In the event that non-production material is used in or as the test item, document the differences between that material and the expected production item.

b. At the proper test location, place and secure the test item in the configuration established during the pre-test analysis (para 3.1). Ensure that the test item is placed such that the test can verify that the designed blast hardening measures do provide the intended protection from the blast environment.

c. Instrument the test item according to the data instrumentation requirements established during the pre-test

analysis (para 3.2.3). Confirm the placement of the free field instrumentation, and verify that the data acquisition system is operational. All instrumentation (strain gages, accelerometers, and pressure gages) and data acquisition system calibration data must be documented. To the extent possible, baseline the test item again while in the test setup.

d. Document the test item placement and instrumentation locations by test layout drawings and/or taking photographs/video of the test bed setup.

e. Ensure that high speed motion photography cameras are properly aimed and ready, have proper lighting and exposure settings, and if necessary, correct sun angle.

f. Reverify that the simulation facility is set up to provide the correct environmental levels for the test item/configuration being tested.

g. Confirm that the test item is in the proper operational mode if applicable. Perform final checkouts.

h. Verify that precautionary measures have been taken to contain the possible spillage or dispersement of any hazardous materials which may be found on the test item. Recovery and cleanup procedures must be clearly outlined in the test plan (para 3.3d).

i. Perform test.

j. Repeat above procedures for each test performed.

4.2.2 Post-test Checkout

a. Once it is safe to approach the test item, an overall visual inspection of the test item must be performed as soon as possible. The post-test condition of the test item should be recorded in a log book and photographed/video taped.

b. The following should be inspected:

(1) The condition of the blast hardening measures. Are outriggers, guy wires, or protective plates damaged? Are they functional? Can they be repaired or easily replaced? If damaged, how do they affect operations and mission accomplishment of the test item?

(2) The condition of the test item's main structure. Were any test item components damaged? Was damage caused by the overpressure, dynamic pressure, or secondary airborne debris? Was the test item translated, rotated, or overturned? Damage associated with compression/crushing is typically due to the overpressure forces, and damage associated with test item translation or airborne debris is due to the dynamic pressure forces.

(3) The test item's functionality. If applicable, is the test item operating If not, what caused loss of opertions and can it be made operational? Is the test item operational? If not, is it repairable? Does the test item meet the failure criteria established in paragraph 3.1.2a?

(4) Instrumentation condition. Are all gages mounted and intact? Are data cables properly attached and undamaged?

c. The results of all the post-test checkouts should be recorded in TIRs. A blank TIR form is provided in Appendix E. "Good News" TIRs may be written to document successful results or completion of a test phase.

4.2.3 Data Required

a. Description and findings of the pre-test analysis and simulations.

b. Detailed description of the test item to include the following

(1) Serial number
(2) Serial numbers for subcomponents (if applicable)
(3) Dimensions
(4) Material Composition
(5) MSDSs (if applicable)
(6) Photograph/video of pre-test condition
(7) Mechanical Drawings
(8) Operating status and recovery procedures

c. Detailed description of all inspections, performance and operational baseline checks.

d. Detailed description of the test facility and the method used to produce the blast environment.

e. Results of the blast overpressure and dynamic pressure environment measurements with the pressures expressed in kilo Pascals (kPa), and pressure durations expressed in seconds (sec).

f. Results of the data instrumentation measurements monitoring the test item response.

g. Results and photographs/video of all pre-test and post-test visual inspections and functional checkouts, and recovery procedures.

h. Calculated impulses (kpa-sec) for the peak static and dynamic pressures.

i. Results and photographs/video of all pre- and post-test visiual inpsections and functional checkouts.

j. Film of high speed motion cameras.

k. Results of any recovery or repair efforts, and copies of the TIRs.

l. Detailed description of test item configurations tested.

m. Detailed description of the data acquisition system to include calibration, accuracy, and percent error for all data acquisition equipment.

n. Detailed descriptions of gages and mount locations to include photographs/video.

4.3 <u>Synergistic Effects</u>

4.3.1 Test Setup

a. Baseline the test item by conducting a visual inspection of the overall test item configuration and specifically noting the condition of all the HCIs identified in the pre-test analysis (para 3.1.1). Any applicable functional checkouts must be performed during the test setup. Photographs/video of the test item should be taken to document the item's pre-test condition. Document the type and condition of any thermal and blast hardening measures used in the test item's design (para 4.1.1a and 4.2.1a) as well as inherent hardening features.

b. At the proper test location, place and secure the test

item in the configuration established during the pre-test analysis (para 3.1). Ensure that the test item is placed such that the test can verify that the designed thermal and blast hardening measures do provide the intended protection from the combined thermal and blast environments.

c. Instrument the test item according to the data instrumentation requirements established during the pre-test analysis (para 3.2.2 and 3.2.3). Confirm the placement of the free field instrumentation, and verify that the data acquisition system is operational. All instrumentation and data acquisition system calibration data must be documented. To the extent possible, baseline the test item again while in the test setup.

d. Document the test item placement and instrumentation locations by test layout drawings and/or taking photographs/video of the test bed setup.

e. Reverify that the simulation facility is set up to provide the correct environmental levels for the test item/configuration being tested. Reverify that the separation time between the thermal pulse and the arrival of the blast wave is appropriate for the threat environment being simulated.

f. Confirm that the test item is in the proper operational mode if applicable. Perform final checkouts.

g. Verify that precautionary measures have been taken to contain the possible spillage or dispersement of any hazardous materials which may be found on the test item. Recovery and cleanup procedures must be clearly outlined in the test plan (para 3.3d).

h. Perform test.

i. Repeat above procedures for each test performed.

4.3.2 Post-test Checkout

a. Once it is safe to approach the test item, an overall visual inspection of the test item must be performed as soon as possible. The post-test condition of the test item should be recorded in a log book or data sheet and photographed/video taped.

b. The following should be inspected:

(1) The condition of the thermal and blast hardening measures as suggested in paragraphs 4.1.2 and 4.2.2.

(2) The condition of the test item's main structure as suggested in paragraphs 4.1.2 and 4.2.2.

(3) The test item's functionality. If applicable, is the test item operating? If not can it be returned to an operating condition? Is the test item operational? If not, is it repairable? Does the test item meet the failure criteria established in paragraph 3.1.2a?

(4) Instrumentation condition. Are all gages mounted and intact? Are data cables properly attached and undamaged?

c. The results of all the post-test checkouts should be recorded in TIRs. A blank TIR form is provided in Appendix E. "Good News" TIRs may be written to document successful results of completion of a test phase.

4.3.3 Data Required

a. Description and findings of the pre-test analysis and simulations.

b. Detailed description of the test item to include the following:

(1) Serial number
(2) Serial numbers for subcomponents (if applicable)
(3) Dimensions
(4) Material Composition
(5) MSDSs (if applicable)
(6) Photograph/video of pre-test condition
(7) Mechanical drawings
(8) Operating status and recovery procedures

c. Detailed description of all inspections, performance and operational base line checks.

d. Detailed description of the test facility and the method used to produce the thermal radiation and blast environments.

e. Results of the simulated test environment measurements as described in paragraphs 4.1.3 and 4.2.3.

f. Results of the data instrumentation measurements monitoring the test item response.

g. Results and photographs/video of all pre-test and post-test visual inspections and functional checkouts.

h. Copies of the TIRs.

i. Detailed description of test item configurations tested.

j. Detailed description of the data acquisition system to include calibration, accuracy, and percent error for all data acquisition equipment.

5.0 PRESENTATION OF DATA

5.1 Criteria Compliance.

a. A direct comparison must be presented between the test environment achieved during testing and the environment criteria as presented in the Nuclear Survivability/Hardening Criteria document for the item being tested.

b. Any difference(s) between the test environment and the criteria environment parameters (>10%) should be analyzed to assess the impact on the validity of the overall test results, determine the correction factors for the results, and the need for additional analysis and/or testing.

5.2 Test Results

a. Intended data reduction and final calculation procedures should be clearly documented and presented in the appendices of the test plan.

b. A direct comparison must be made between the pre-test analysis results and the actual test results. Major differences between the two must be further analyzed.

c. Test data must be presented in a clear and concise manner using a combination of charts, graphs, tables, drawings, and photographs.

d. Tables may be used to present the following data:

(1) Equipment Test Matrix

(2) Pre-test analysis data
(3) Test point data
(4) Pre-test analysis and test point data comparisons

e. Charts and graphs may be used to present the following data:

(1) Test Environment data
(2) Pre-test analysis and test point data comparisons
(3) Test schedules

f. Drawings and photographs may be used to present the following data

(1) Test setup
(2) Test item configurations
(3) Instrumentation locations
(4) Data acquisition system setup
(5) Visible damage

5.3 Configuration Survivability

a. During testing, situations may arise which prohibit conduct of the test with the test item in the baseline configuration. The baseline configuration is defined as the configuration in which the test item is most likely to be produced and operated by the user or the set of conditions/ procedures under which the test item is required to function. Plus, the test item may not be a full representation of the overall system under test; for example, scale models or sections of the overall system may be used as the test item. Therefore, a comparison must be conducted between the test article's baseline configuration and setup and the actual test article's test configuration and setup. Any differences between the test configuration and the baseline configuration must be identified, documented and analyzed for effects on the test results. Both the test and baseline configuration must be stored in the system's life-cycle database for future reference.

b. The test results must then be examined for effects from any differences in the baseline and test configurations. If any effects on the response data are identified due to these configurational differences, the test results must be analyzed and corrected to reflect the corresponding test item's baseline configuration response.

c. The final survivability determination is on the baseline configuration vs the system's criteria. All test item survivability statements must address the effects of any differences between the baseline configuration and the test configuration and reflect the expected test item's survivability in the baseline configuration in the criteria environments.

5.4 Life-Cycle Database

a. Technical Data and Results. A life-cycle database must be maintained of all technical data and test results for every test item configuration tested. All information must be clearly identifiable with the baseline as well as each test configuration.

b. Baseline Configuration. Changes in the baseline configuration must be documented and reviewed to identify their effect on previous test results, the need for additional testing, and, survivability determination on the new configuration.

Appendix A
Nuclear Survivability Directive

1.0 Policy Documents

1.1 Department of Defense Instruction 5000.2, Defense Acquisition Management Policies and Procedures, 23 Feb 91[a], establishes that all major and non-major systems that perform critical missions will be survivable to nuclear weapon effects. Each of the services has in turn developed their own regulation or instruction document implementing the DoD Directive: Army Regulation 70-75, Survivability of Army Personnel and Materiel[b]; Air Force Regulation 80-38, Air Force Systems Survivability Program[c]; and OPNAV Instruction 3401.3A, Nuclear Survivability of Navy and Marine Corps Systems[d].

1.2 The policy established by the documents given above instructs that the nuclear survivability issues of a system will be included in all phases of the acquisition process: Concept Exploration, Concept Demonstration and Validation, Full Scale Engineering Development, Production, and Deployment.

1.3 The responsibility for achieving and verifying a system's nuclear survivability is placed upon the Program Manager. The Program Manager's Office (PMO) is therefore responsible for developing a Nuclear Survivability Program which assures that the nuclear survivability requirements have been addressed since the system's concept exploration phase and are maintained throughout deployment. The Program Management Handbook on Nuclear Survivability, November 1990[e] provides comprehensive guidance on the development of a Nuclear Survivability Program.

1.4 There are several approaches that may be used to achieve nuclear survivability. These include nuclear hardness, avoidance, proliferation, redundancy, reconstitution and deception. All approaches should be considered before nuclear hardening is implemented.

1.4.1 Nuclear hardness constitutes achieving inherent physical and electrical characteristics that will allow the system to perform it's mission during and/or after being subjected to Nuclear Weapons Effects (NWE).

1.4.2 A description of each of the other approaches for achieving nuclear survivability is provided in Appendix B.

1.4.3 Each approach should be considered so that the most cost effective combination is implemented to meet the system's survivability requirements.

2.0 Life Cycle Hardness Surveillance

2.1 Once it is determined that nuclear hardening is going to be implemented as part of the Nuclear Survivability Program, the PMO, independent evaluator and tester, and the system contractor must conduct design review sessions to evaluate the nuclear hardness characteristics and requirements of each system component. It is during this review process that HCIs are identified; HCIs are structural, mechanical, electrical, and electronic components which provide protection from a specific nuclear environment or are required to operate under nuclear environmental stresses.

2.2 The design analysis performed to determine a system's inherent hardness must be validated by NWE testing to provide a significant confidence that all units will meet the hardness requirements. Testing also confirms the design safety margins determined during analysis.

2.3 The PMO and system contractor must also develop a Hardness Assurance, Maintenance, and Surveillance (HAMS) Program. Under the HAMS Program, the Hardness Assurance Plan ensures that the production process does not degrade the system's inherent or designed hardness, and the Hardness Maintenance and Surveillance Plans maintain the hardness levels after deployment. The HAMS Program relies on both design analysis and NWE testing for a comprehensive system hardness evaluation.

2.4 Test hardware allocation must be conducted early in the HAMS program so that an adequate number of test items will be available to perform a complete nuclear hardness validation test.

2.5 Monitor and evaluate all changes to baseline configuration to ensure proposed changes do not degrade the survivability level to an unacceptable degree.

2.6 Update and maintain baseline configuration and database.

APPENDIX B
NUCLEAR SURVIVABILITY APPROACHES

1.0 AVOIDANCE - This approach constitutes taking measures to escape being subjected to a nuclear weapon attack. This would include measures such as fielding the system only in areas where a nuclear weapon attack is very unlikely to occur.

2.0 PROLIFERATION - Proliferation requires that extra systems be produced to defray anticipated losses from a nuclear weapon attack. This approach is based on having more systems than are necessary to accomplish a specific mission such that if a battle area is attacked by a nuclear weapon enough systems will survive to complete the mission.

3.0 REDUNDANCY - Redundancy is the use of multiple paths/means of accomplishing the same task to prevent the loss of a capability if one or more of the paths/means are eliminated.

4.0 RECONSTITUTION - This approach requires the system be designed to allow rapid recovery, resupply, remanning, or repair of the affected components. An example of this would be incorporating in the design an easy access reset switch to overcome upset caused by electromagnetic pulse.

5.0 DECEPTION - Deception consists of operational measures, such as camouflage, which deceive the enemy about the system's actual location and thereby prevent it from being targeted.

6.0 HARDENING - Nuclear Hardening consists of improving the physical attributes of the system to permit survival in a given environment. Examples would be to increase the strength of the exterior surface to be more blast resistant or to increase the thermal reflectivity of the exterior surface to reduce the thermal energy absorbed consistent with IR signature requirements.

APPENDIX C
NUCLEAR THERMAL ENVIRONMENT

1.0 The following summary is an excerpt from Department of the Army Pamphlet No. 50-3, THE EFFECTS OF NUCLEAR WEAPONS[†].

1.1 One of the important differences between a nuclear and a conventional high-explosive weapon is the large proportion of the energy of a nuclear explosion which is released in the form of thermal (or heat) radiation. Because of the enormous amount of energy liberated per unit mass in a nuclear weapon, very high temperatures are attained. The temperatures are estimated to be several tens of million degrees, compared with a few thousand degrees in the case of a conventional explosion. For practical purposes, it is estimated that 35 percent of the total yield of an air burst is emitted as thermal radiation energy. This means that for every 1 kiloton TNT equivalent of energy release, about 0.35 kiloton, i.e., 3.5×10^{11} calories or about 410,000 kilowatt-hours, is in the form of thermal radiation. The thermal radiation leaving the fireball covers a wide range of wavelengths, from the short ultraviolet, through the visible, to the infrared region.

1.2 The curves in Figure C-1 show the variation with the scaled time, t/t_{max}, of the scaled fireball power, P/P_{max}, and of the percent of the total thermal energy emitted, E/E_{tot}, in the thermal pulse of an air burst. The time after the explosion for the temperature maximum in the second thermal pulse is t_{max}, P_{max} is the maximum rate (at t_{max}) of emission of thermal energy from the fireball, and E_{tot} is the total thermal energy emitted by the fireball.

1.3 The extent of injury or damage caused by thermal radiation or the chance of igniting combustible material depends to a large extent upon the amount of thermal radiation energy received by a unit area of exposed material within a short interval of time. The thermal energy falling upon a given area from a specified explosion will be less farther from the explosion, for two reasons: (1) the spread of the radiation over an ever increasing area as it travels away from the fireball, and (2) attenuation of the radiation in its passage through the air. If the radiation is distributed evenly in all directions, then at a distance D from the explosion the same amount of energy will fall upon each

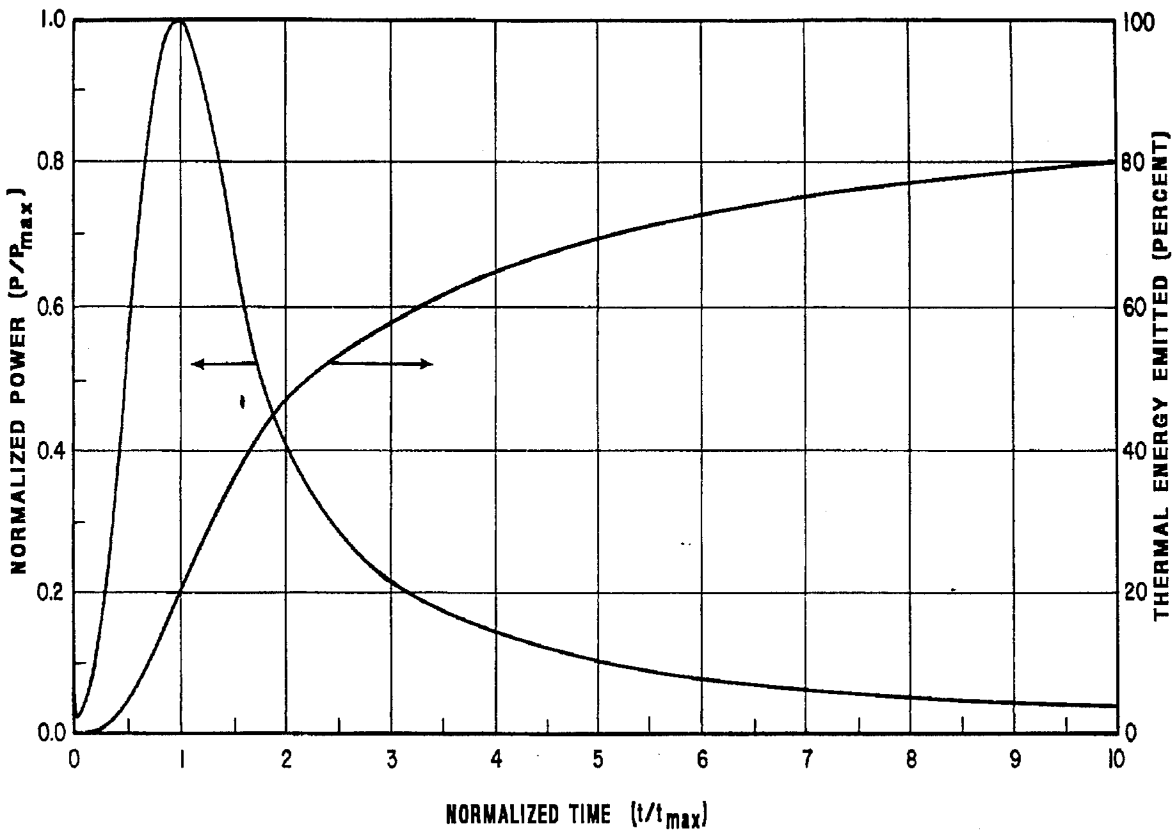

FIGURE C-1. Scaled (or normalized) fireball power and fraction of thermal energy emitted versus scaled (or normalized) time in the thermal pulse of an air burst below 100,000 ft

unit area of the surface of a sphere of radius D. The energy received per unit area at a distance D would be $E/4\pi D^2$ where E is the thermal radiation energy produced in the explosion. This quantity varies inversely as the square of the distance from the explosion. In order to estimate the amount of thermal energy actually reaching the unit area, allowance must also be made for the attenuation of the radiation by the atmosphere. This attenuation is due to two main causes: absorption and scattering. Atoms and molecules present in the air are capable of absorbing certain portions of the thermal radiation.

Absorption is most effective for the shorter wavelength rays. Attenuation as a result of scattering occurs with radiations of all wavelengths. Scattering can be caused by molecules present in the air but is much more effective when caused by the reflection and diffraction of light rays by particles of dust, smoke, or fog in the atmosphere. Scattering leads to a diffused rather than direct transmission of the thermal radiation.

1.4 When thermal radiation falls upon any material or object, part may be reflected, part will be absorbed, and the remainder, if any, will pass through and ultimately fall upon other materials. It is the radiation absorbed by a particular material that produces heat and so determines the damage suffered by that material. The extent or fraction of the incident radiation that is absorbed depends upon the nature and color of the material or object. Highly reflecting and transparent substances do not absorb much of the thermal radiation and so they are relatively resistant to its effects. An important factor in connection with material damage due to thermal radiation is the rate at which the thermal energy is delivered. For a given total amount of thermal energy received by each unit area of exposed material, the damage will be greater if the energy is delivered rapidly than if it were delivered slowly.

1.5 The amount of thermal energy falling upon a unit area exposed to a nuclear explosion depends upon the total energy yield, the height of burst, the distance from the explosion, and the atmospheric conditions. Although extensive studies have been made of the effects of thermal radiation on a large number of individual materials, it is difficult to summarize the results because of the many variables that have a significant influence.

1.6 However, a general description of the effect on various common materials can be provided. Fabrics made of natural fibers, e.g., cotton and wool, and some synthetic materials, e.g., rayon, will scorch, char, and perhaps burn; nylon, on the other hand, melts, when heated to a sufficient extent. Wood is charred by exposure to thermal radiation, the depth of the char being closely proportional to the radiant exposure. For sufficiently large amounts of energy per unit area, wood in some massive forms may exhibit transient flaming but persistent ignition is improbable under the conditions of a nuclear explosion. However, in a more-or-less finely divided form, such as sawdust, shavings, or excelsior, or in a decayed, spongy state, wood can be ignited fairly readily. Glass is highly

resistant to heat, but as it is very brittle it is sometimes replaced by transparent or translucent plastic materials or combined with layers of plastic to make it shatterproof. These plastics are organic compounds and so are subject to decomposition by heat. Surface melting or darkening can be expected at thermal energy levels of at least 60 to 70 cal/cm^2. Metal structures are primarily affected by a weakening of the metal's yield strength due to an increase in temperature from the absorbed heat. Heat absorbing paint is commonly used to protect metal structures from thermal radiation. The burning or charring paint absorbs the heat and thus protects the underlying metal surface; plus, the smoke produced screens the surface from further exposure.

APPENDIX D
NUCLEAR BLAST ENVIRONMENT

1.0 The following summary is an excerpt from Department of the Army Pamphlet No. 50-3, THE EFFECTS OF NUCLEAR WEAPONS.

1.1 The expansion of the intensely hot gases at extremely high pressures in the fireball of a nuclear weapon explosion causes a shock wave to form, moving outward at high velocity. Most of the material damage caused by a nuclear explosion at the surface or at a low or moderate altitude in the air is due to the shock (or blast) wave which accompanies the explosion.

1.2 It is of interest to examine the changes of overpressure and dynamic pressure with time at a fixed location (See Fig D-1). For a short interval after the detonation, there will be no change in the ambient pressure because it takes some time for the blast wave to travel from the point of the explosion to the given location. This time interval known as arrival time depends upon the energy yield of the explosion and the slant range. When the shock front arrives at the observation point, the overpressure (the excess pressure over the atmospheric pressure) will increase sharply from zero to its maximum (peak) value. Subsequently, the overpressure decreases. The overpressure drops to zero in a short time, and this marks the end of the positive phase. The duration of the overpressure positive phase increases with the energy yield and the distance from the explosion.

1.3 Provided the observation point is at a sufficient distance from the explosion, the overpressure will continue to decrease after it falls to zero so that it becomes negative. During this negative phase, the pressure in the shock wave is less than the ambient atmospheric pressure. After decreasing gradually to a minimum value, the pressure starts to increase until it becomes equal to the normal atmospheric pressure, and the overpressure is zero again.

1.4 The destructive effects of the blast wave are frequently related to values of the peak overpressure, but there is another important quantity called the "dynamic pressure." The dynamic pressure is proportional to the square of the wind velocity and to the density of the air behind the shock front. It is a measure of the kinetic energy of a certain volume of air behind

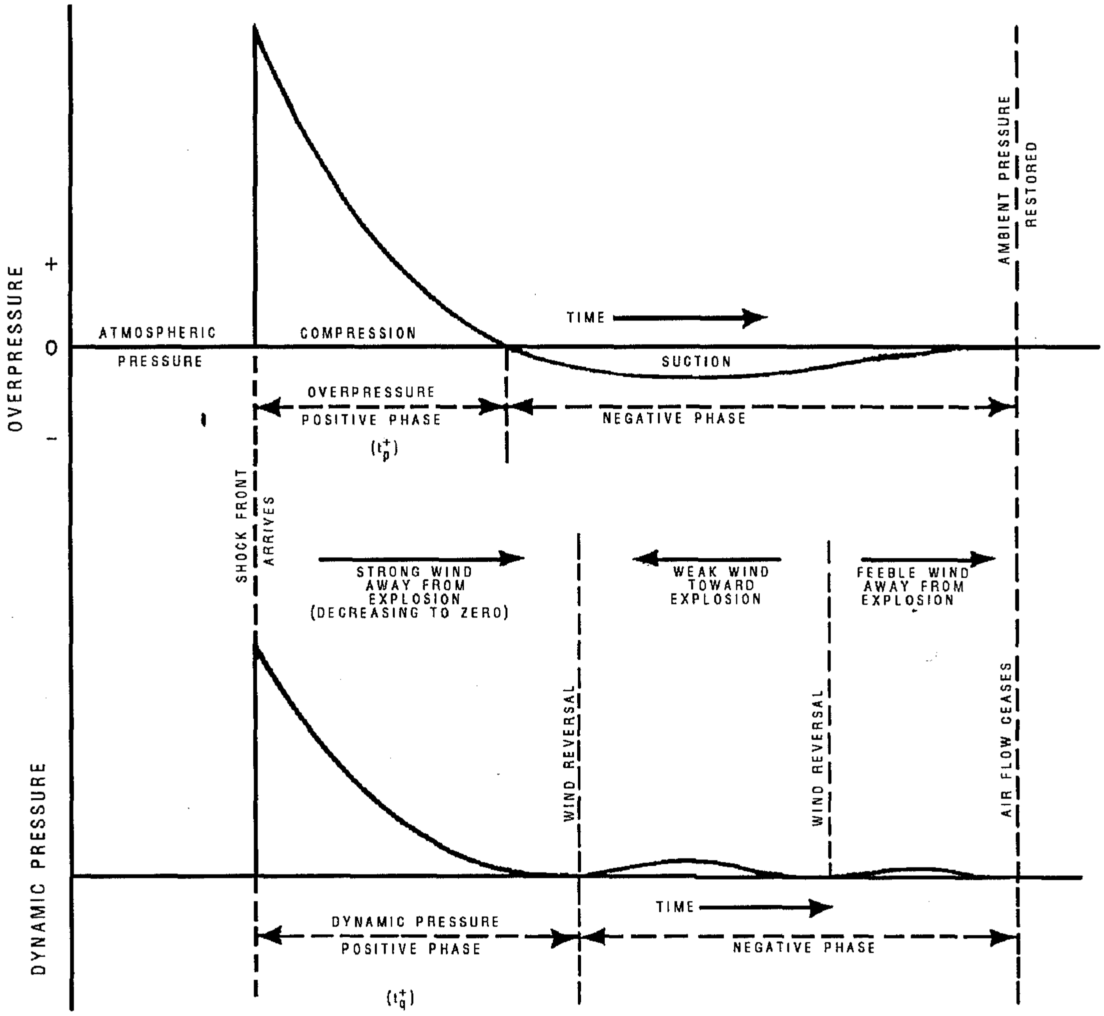

FIGURE D-1. Variation of overpressure and dynamic pressure with time at a fixed location

the shock front. For a great variety of building and vehicle types, the degree of blast damage depends largely on the drag force associated with the strong winds accompanying the passage of the blast wave. Changes in the wind and in the associated dynamic pressure accompany the changes with time of the

overpressure. Nearly all the direct damage caused by both overpressure and dynamic pressure occurs during the positive overpressure phase of the blast wave.

1.5 A structure is subjected to three different types of loading due to the blast wave: diffraction, compression, and drag. Diffraction loading is the force produced on the faces of a structure as the blast wave engulfs the structure completely. The pressure differential on the faces of the structure produces a lateral (or translational) force tending to cause the structure to deflect and move in the direction of the blast wave. Once the blast wave completely engulfs the structure, the diffraction loading is replaced by an inwardly directed pressure which produces compression loading. During the whole of the overpressure positive phase a structure will be subjected to the dynamic pressure loading (drag loading) which will also produce a translational force in the direction of the blast wave velocity. Under nonideal surface conditions a blast wave precursor may form and subject a structure to a dynamic pressure drag loading of varying strength prior to the maximum overpressure diffraction loading.

1.6 Except at high blast overpressures, the dynamic pressures at the face of a structure are much less than the peak overpressures due to the blast wave and its reflection. However, the drag loading on a structure persists for a longer period of time, compared to the diffraction loading.

1.7 Attention may be called to an important difference between the blast effects of a nuclear weapon and those due to a conventional high-explosive bomb. In the former case, the combination of high peek overpressure, high wind (or dynamic) pressure, and longer duration of the positive (compression phase of the blast wave results in mass distortion of buildings, similar to that produced by earthquakes and hurricanes. An ordinary explosion will usually damage only part of a large structure, but the blast from a nuclear weapon can surround and destroy whole buildings in addition to causing localized structural damage. Thus, it is the effect of the duration of the drag loading on structures which constitutes an important difference between nuclear and high-explosive detonations. For the same peak overpressure in a blast wave, a nuclear weapon will prove to be more destructive than a conventional one, especially for structures which respond to drag loading. This is because the blast wave is of much shorter duration for a high-explosive

weapon. As a consequence of the longer duration of the positive phase of the blast wave from weapons of high energy yield, such devices cause more damage to drag sensitive structures than might be expected from the peak overpressures alone.

APPENDIX E
TEST INCIDENT REPORT FORM

Distribution authorized to the Department of Defense and DoD contractors only. Other requests shall be referred to the test sponsor. (see block 6 below)	
TEST INCIDENT REPORT (AR 73-1)	1. Release Date: REV #:
Test Title: 2.	Test Project #: 3. | TIR #: 4.
5. Test Agency: 7. System:	6. Test Sponsor: 8. Original Release Date:
I MAJOR ITEM DATA	
10. Model: 11. Serial #: 12. USA #: 13. Mfr: 14. Contract #: 15. Item #:	Test Life: Units: 21. 22. 23. 24. 25.
II INCIDENT DATA	
30. Title: 31. Subsystem: 32. Incident Class: 33. Observed During: 34. Action:	40. Date & Time: 41. FD/SC Step #: 42. FD/SC Class #: 43. Chargeability: 44. Incident Status:
46. Categories: 47. Keywords:	
Test Environment: 48. 49. Disposition:	Type: | Condition:
III INCIDENT SUBJECT DATA	
50. Name: 51. Serial #: 52. FSN/NSN: 53. Mfr: 54. Mfr Part #:	60. FGC: 61. LSA #: Part Life: Units: 62. 63.

(continued on next page)

TIR Number: REV	Page Number: 2
55. Drawings #: 56. Quantity: 57. Action: 58. (NOT USED)	64. 65. Next Assy: 66. Serial #: 67. Software Version #:

IV MAINTENANCE DATA

70. Diagnostic Clockhours: 71. Diagnostic Manhours: 72. Total Maint Clockhours: 73. Total Maint Manhours:	80. Type: 81. Level Used: 82. Level Prsc: 83. Level Recm:

V INCIDENT DESCRIPTION

90.

MAINTENANCE TIME BREAKDOWN

DateSt	DateEd	TmSt	TmEd	Level	Delay	Type	Dgchrs	Tmchrs	Dgmhrs	Tmmhrs	App

PARTS REPLACED DATA

Nomenclature	FGC	(Numbering control used)	Partlife	Level	Qty	Action

Name, Title & Phone of Preparer:	Releaser:
98.	99.

DA Form XXXX-E ADACS#:

APPENDIX F
ACRONYMS

DA	Department of the Army
DATTS	Directorate for Applied Technology, Test and Simulation
DoD	Department of Defense
FWHM	Full Width/Half Maximum
HAMS	Hardness Assurance, Maintenance, and Surveillance
HCI	Hardness Critical Item
LB/TS	Large Blast Thermal Simulator
MSDS	Material Safety Data Sheet
NWE	Nuclear Weapons Effects
PAM	Pamphlet
PMO	Program Manager's Office
TIR	Test Incident Report
TOP	Test Operations Procedure

APPENDIX G
REQUIRED REFERENCES

1. Technical Report, DASIAC-SR-92-006, Guide to Nuclear Weapons Effects Simulation Facilities and Techniques - 1992 Edition, Defense Nuclear Agency, April 1993

2. DA Pamphlet, DA PAM 73-1, 16 Oct 92

References For Information Only

a. Department of Defense Instruction 5000.2, Defense Acquisition Management Policies and Procedures, 23 Feb 91

b. Army Regulation 70-75, Survivability of Army Personnel and Materiel,
10 Jan 95

c. Air Force Regulation 80-38, Air Force Systems Survivability Program, 29 September 1989

d. OPNAV Instruction 3401.3A, Nuclear Survivability of Navy and Marine Corps Systems, 5 January 1989

e. Handbook, DNA-H-90-30, Program Management Handbook on Nuclear survivability, November 1990

f. Pamphlet 50-3, The Effects of Nuclear Weapons, Department of the Army, March 1977

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to Commander, U.S. Army Test and Evaluation Command, ATTN: AMSTE-TM-T, Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Directorate for Applied Technology, Test, and Simulation, ATTN: STEWS-DATS-AC, White Sands Missile Range, NM 88002-5158. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.

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U.S. Army Test & Evaluation Command

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D. PREPARED UNDER CONTRACT NUMBER

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